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Changes in Body Temperatures during Prolonged Physical Exercise and their Influence on Muscle Metabolism in Dogs*

Increasing body temperature during physical work is one of the important factors limiting endurance performance (*Adams et al.*, 1975; *Mac Dougall et al.*, 1974; *Pugh et al.*, 1967; *Saltin et al.*, 1972; *Schmidt, Brück*, 1981). The mechanism of this effect is not fully understood. It is known, however, that exercise-hyperthermia considerably alters circulatory and respiratory responses to exercise; it may also impair some regulatory functions of the brain, and affect motivation to continue the work.

There are some data demonstrating that high temperatures, but within physiological limits, lower phosphorylative efficiency of mitochondria in skeletal muscle in vitro (*Brooks et al.*, 1971) and in vivo increase the glycolytic rate in muscle during isometric contractions (*Edwards et al.*, 1972).

Previous results from this laboratory (*Kozlowski et al.*, 1983, unpublished data) provided evidence that prevention of hyperthermia during prolonged exercise in dogs increases work endurance, slows down glycogen depletion in working muscles and causes an increase in blood lactate concentration. This suggested that exercise-induced hyperthermia might reduce working ability by its effect on muscle metabolism.

The aim of this work was to study the effect of external cooling during exercise on changes in body temperatures, heart and respiratory frequencies as well as on some indices of muscle metabolism in dogs.

MATERIAL AND METHODS

Experimental procedure. The investigations were carried out on 16 male dogs weighing 15—21 kg, familiarized with the treadmill running. The dogs performed exercise of moderate intensity (slope 12°, speed 4.3—5.8 km/h) until exhaustion, at ambient temperature 22 ± 1 °C and relative air humidity 55 ± 5 %, first without (control), and then a few days later with external cooling. During exercises the dogs were wearing canvas jackets with pockets filled either with sand (2 kg) or with crashed ice (2 kg), packed in tightly closed plastic bags in experiments without and with cooling respectively.

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Table 1

Changes in body temperatures, heart rate (HR), respiratory frequency (R_f) and plasma osmolality during exhausting exercise performed by the same dogs with and without cooling (means ± SE)

Variables measured	Exercise without cooling		Exercise with cooling		
	Before	End	Before	End of control exercise	End
T_{re} (°C)	39.7 ± 0.1	42.4 ± 0.3	39.3 ± 0.2	40.7 ± 0.4++	41.2 ± 0.5
T_m (°C)	39.1 ± 0.2	43.1 ± 0.3	39.2 ± 0.1	41.2 ± 0.5++	41.7 ± 0.4
T_{hy} (°C)	39.4 ± 0.1	41.5 ± 0.4	39.0 ± 0.2	40.1 ± 0.3++	40.7 ± 0.3
HR (beats/min)	99 ± 14	278 ± 31	103 ± 21	221 ± 24+	203 ± 10
R_f (breaths/min)	54 ± 27	331 ± 4	33 ± 3	270 ± 18+	276 ± 12
Plasma osmolality (mosm/kg)	294 ± 1	299 ± 4	295 ± 2	298 ± 4	298 ± 5

Significant differences between values obtained during exercise with and without cooling: $p < 0.05$+, $p < 0.01$++

Table 2

Changes in body temperature, blood lactate (LA) concentration, and muscle metabolite contents during exhausting exercise performed by the same dogs with and without cooling (means ± SE)

	Exercise without cooling		Exercise with cooling		
Variables measured	Before	End	Before	End of control exercise	End
T_{re} (°C)	39.4 ± 0.2	41.8 ± 0.2$^{\times\times}$	39.0 ± 0.1	40.8 ± 0.2$^{\times\times++}$	41.1 ± 0.3$^{\times\times}$
T_m (°C)	39.7 ± 0.2	43.0 ± 0.2$^{\times\times}$	39.3 ± 0.2	41.8 ± 0.1$^{\times\times++}$	42.1 ± 0.2$^{\times\times}$
Blood LA (mmol/l)	1.52 ± 0.13	3.53 ± 0.26$^{\times\times}$	1.34 ± 0.12	2.82 ± 0.39$^{\times\times+}$	3.04 ± 0.45$^{\times\times}$
Muscle LA (mmol/kg d.m.)	6.5 ± 0.6	82.5 ± 8.0$^{\times\times}$	5.8 ± 0.5	42.5 ± 3.4$^{\times\times++}$	46.3 ± 3.8$^{\times\times}$
ATP (mmol/kg d.m.)	23.5 ± 0.9	18.6 ± 2.1$^{\times}$	23.1 ± 0.8	22.9 ± 1.3	22.7 ± 1.5
ATP/ADP	10.0 ± 0.6	6.7 ± 1.2$^{\times\times}$	9.5 ± 0.7	7.8 ± 0.5	7.5 ± 0.5$^{\times}$
AMP (mmol/kg d.m.)	0.18 ± 0.02	0.40 ± 0.09$^{\times\times}$	0.15 ± 0.01	0.18 ± 0.01$^{\times++}$	0.20 ± 0.01$^{\times}$
CP (mmol/kg d.m.)	85.8 ± 4.4	49.9 ± 4.8$^{\times\times}$	82.4 ± 2.7	68.5 ± 5.6$^{\times++}$	67.9 ± 5.1$^{\times}$
Glycogen (mmol/kg d.m.)	397.2 ± 41.3	161.5 ± 27.9$^{\times\times}$	349.7 ± 34.8	231.0 ± 28.8$^{\times\times+}$	183.9 ± 31.5$^{\times\times}$

Significant differences between values obtained during exercise with and without cooling: $p < 0.05^{+}$, $p < 0.01^{++}$
Significant differences between resting (initial) and exercise values: $p < 0.05^{\times}$, $p < 0.01^{\times\times}$

Two series of experiments were performed:

In the first series the time of exercise until exhaustion (exercise tolerance), changes in rectal (T_{re}), brain (T_{hy}), and muscle (T_m) temperatures as well as in heart rate (HR), respiratory frequency (R_f) and plasma osmolality were compared in 5 dogs exercising with and without cooling. For measurements of brain temperature each dog had a thermocouple guide tube implanted stereotaxically into the lateral preoptic area of the hypothalamus. T_{re}, T_{hy}, HR and R_f were recorded continuously, whereas T_m was measured before the run, every 30 min of its duration, and at the end of exercise. Venous blood samples were taken at 30-min intervals to determine plasma osmolality. To prevent dehydration water was given ad libitum to the dogs when blood samples were withdrawn.

In the second series exercise tolerance, changes in T_{re} and T_m, blood LA, and some indices of muscle metabolism were compared in 11 dogs performing exercise with and without cooling. Venous blood samples for blood LA determinations were taken before exercise, at the 15th and 30th min of its duration and at the end of run. Since the duration of exercise with cooling was always longer than the control run in the former a blood sample was also taken at the time corresponding to cessation of control exercise.

At the same time intervals needle bioptic samples were taken from the m. vastus lateralis for determinations of ATP, ADN, AMP, phosphocreatine (PC), muscle glycogen and lactate contents. Measurements of physiological variables. All the temperatures were measured by a cooper-constantan thermocouples, R_f was recorded using a strain gauge transducer placed on the dog's thorax, whereas HR was calculated from the RR intervals of the ECG. Blood LA concentration was determined using Boehringer tests (Diagnostica, Mannheim GmbH). Muscle samples were frozen in liquid nitrogen, freeze-dried, powdered and then the $HClO_4$ extracts were analyzed by the enzymatic micro-method (*Harris et al.*, 1974).

RESULTS

First series of experiments. The time of exercise until exhaustion without cooling was 90 ± 15 min, whereas that with cooling 145 ± 14 min ($p < 0.05$). External sooling attenuated the rise in T_{hy}, T_{re} and T_m during exercise in comparison with the control run (Table 1). In both exercises the increases in T_{hy} were lower than those in T_{re} and T_m. The point of exhaustion could not be attributed to attainment of any particular brain, rectal or muscle temperatures. The cooling procedure caused a reduction of the exercise-induced increase in HR and in R_f. No difference in plasma osmolality was found between dogs exercising with and without cooling.

Second series of experiments. The time of exercise until exhaustion without cooling was 57 ± 8.0 min and that with cooling 83 ± 8.5 min ($p < 0.01$). The main results of this series are summarized in Table 2. Similarly as in the first series external cooling significantly reduced exercise-induced increases in both T_{re} and T_m.

In comparison with the control run in the exercise with cooling the enhancement of blood LA concentration and muscle LA content were markedly reduced, whilst muscle glycogen depletion was attenuated. Comparing the muscle high energy phosphates and their derivatives in dogs exercising with and without cooling significant differences were found in the muscle CP and AMP contents. In cooled dogs the muscle CP and AMP contents. In cooled dogs the muscle CP was higher while the muscle AMP content was lower than in control experiments. The muscle ATP content was decreasing progressively during control exercise; during the run with cooling it remained practically constant.

DISCUSSION

The present data provided further evidence that prevention of high increases in body temperature markedly improves work tolerance, prolonging the duration of exercise until exhaustion. Since dehydration of animals was prevented in both exercises the increased duration of running is certainly connected with lower body temperatures, although it cannot be attributed to attainment of any specific rectal, muscle ar brain temperatures. The latter finding does not support the suggestion that high brain temperature is the main cause of the deleterious effect of hyperthermia on working ability (*Cabanac, Caputa*, 1979) at least during moderate exercise performed in thermoneutral environment.

The decreased cardio-respiratory strain in cooled animals may contribute to the improved working ability e.g. by reducing O_2 uptake by respiratory muscles, improving muscle blood flow etc.

The main finding of this work is that modifications of body temperatures during exercise influence muscle metabolism. The following changes can contribute to the earlier exhaustion caused by exercise hyperthermia: 1) accelerated depletion of muscle glycogen content, 2) larger accumulation of muscle lactate resulting in local acidosis, 3) insufficient re-synthesis of high energy phosphates, which shifts the equilibrium values of PC + + ATP, thus decreasing the energy transfer potential.

The locus of the primary disturbance in exercise metabolism caused by hyperthermia is unknown and the relative importance of the abovementioned changes in development of fatigue needs further investigations.

Summarizing: the present study provided evidence that the limiting effect of exercise hyperthermia on working ability may be attributed to disturbances in muscle metabolism.

SUMMARY

Changes in body temperature during prolonged exercise and their influence on muscle metabolism were studied. In comparison with the control run in the exercise with cooling by ice bags the enhancement of blood LA concentration and muscle LA content were reduced, the muscle glycogen depletion was attenuated. The muscle CP was higher while the muscle AMP content was lower than in control experiments. The limiting effect of exercise hyperthermia on working ability may be atributed to disturbances in muscle metabolism.

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ZMĚNY TĚLESNÉ TEPLOTY BĚHEM DLOUHODOBÉHO TĚLESNÉHO CVIČENÍ A JEJICH VLIV NA METABOLISMUS SVALŮ U PSŮ

Souhrn

Práce sleduje změny tělesné teploty psů během dlouhodobého pohybu a jejich vliv na svalový metabolismus. Ochlazení zvířat pomocí vaků s ledem prokázalo oproti kontrolám snížení koncentrace laktátu v krvi a svalu snížení úbytku glyko-

genu, zvýšení hladiny svalového CP a naopak snížení AMP. Limitující účinek námahové hypertermie na pracovní schopnost může být přisouzen změnám ve svalovém metabolismu.

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ИЗМЕНЕНИЯ ТЕМПЕРАТУРЫ ТЕЛА ПРИ ДОЛГОВРЕМЕННОМ УПРАЖНЕНИИ ТЕЛА И ИХ ВЛИЯНИЕ НА МЕТАБОЛИЗМ МЫШЦ СОБАК

Резюме

Работа исследует изменения температуры тела собак при долговременном движении и их влияние на мышечный метаболизм. Охлаждение животных при помощи мешков со льдом показало по сравнению с контролями понижение концентрации лактата в крови и в мышце, понижение уменьшения глюкогена, увеличение уровня мышечного CP и наоборот понижение АМП. Лимитирующее воздействие гипертермии под нагрузкой на работоспособность может быть вызвано изменениями в мышечном метаболизме.

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